(12) UK Patent Application (19) GB (11) 2 042 675 A

(21) Application No 7905418
(22) Date of filing 15 Feb 1979
(43) Application published 24 Sep 1980
(51) INT CL[3] F15D 1/00//F01D 9/00
(52) Domestic classification F2R
(56) Documents cited
GB 1408014
GB 1281899
GB 996041
GB 781482
US 4135857A
(58) Field of search F2R

(71) Applicant
Rolls-Royce Limited, 65 Buckingham Gate, London SW1E 6AT
(72) Inventors
Ian Stewart Kinnear,
Andrew Lawrence May,
Robert Anthony Wall
(74) Agent
J. C. Purcell

(54) Secondary Flow Control in Axial Fluid Flow Machine

(57) Relates to control of secondary flow near surfaces in aerodynamically acting flow passages. Such flow reduces the aerodynamic efficiency of the passages. Specifically applied to an axial turbine to control secondary flow Z between adjacent nozzle guide vanes 6, 8 by modifying part of the platform area 14, 16 to form a surface feature 20 extending transversely of both primary and secondary flows X, Z. An edge of feature 20 deflects part of primary flow X, thus generating vorticity 22 which entrains secondary flow Z and moves downstream to merge with primary flow X. The surface feature may be a step or a groove, Figs 3, 4, not shown.

Fig. 2.

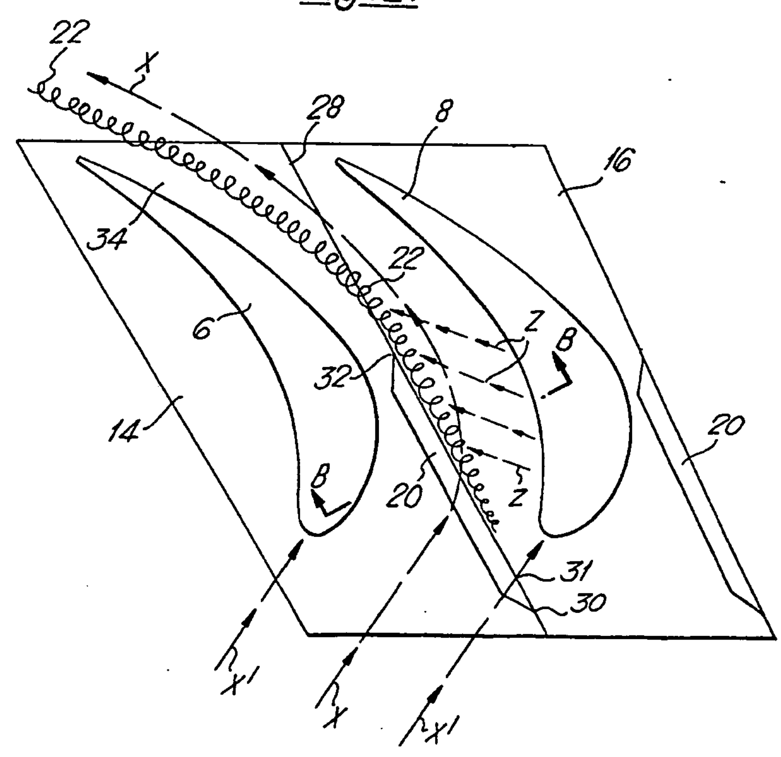


Fig.1.

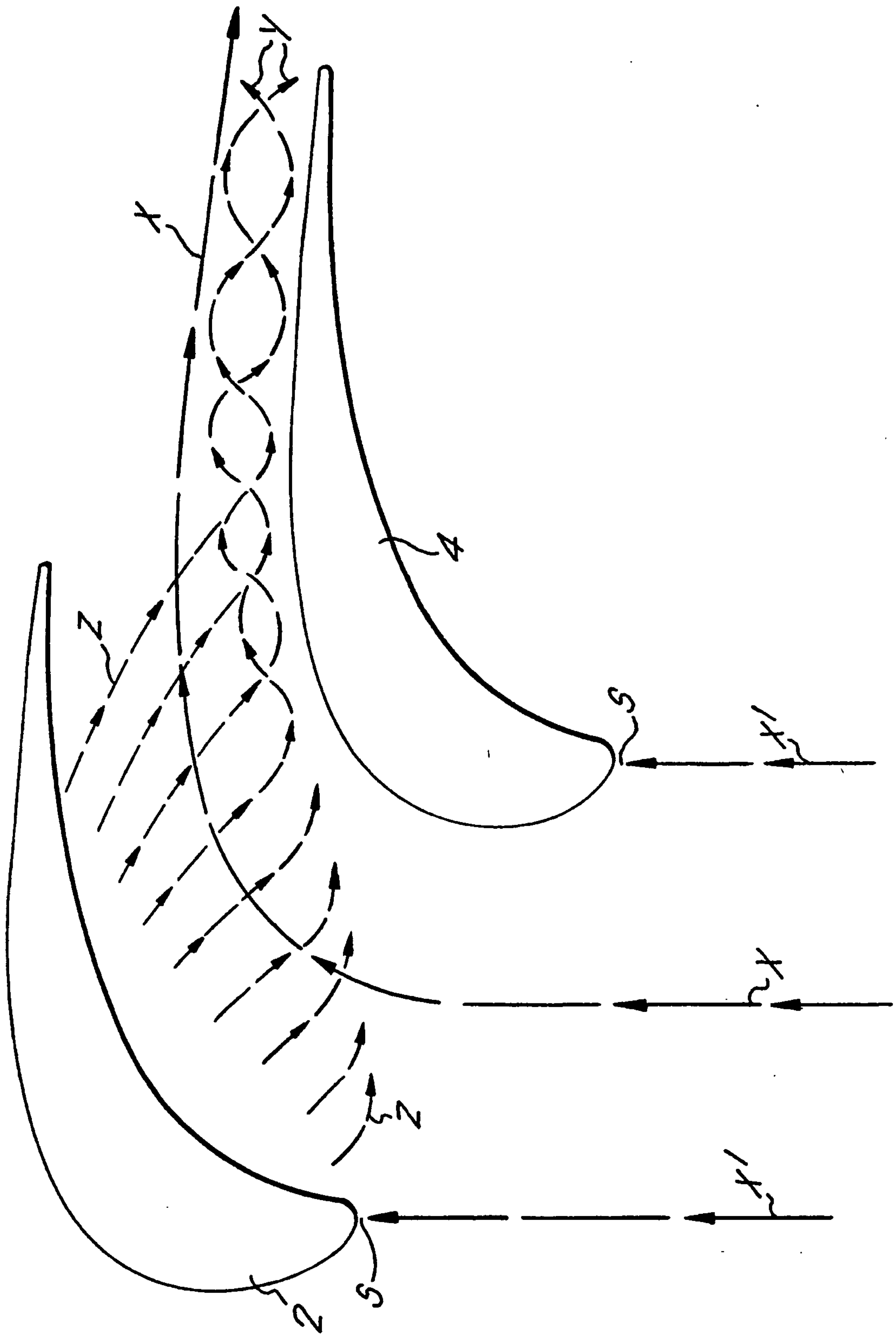


Fig. 2.

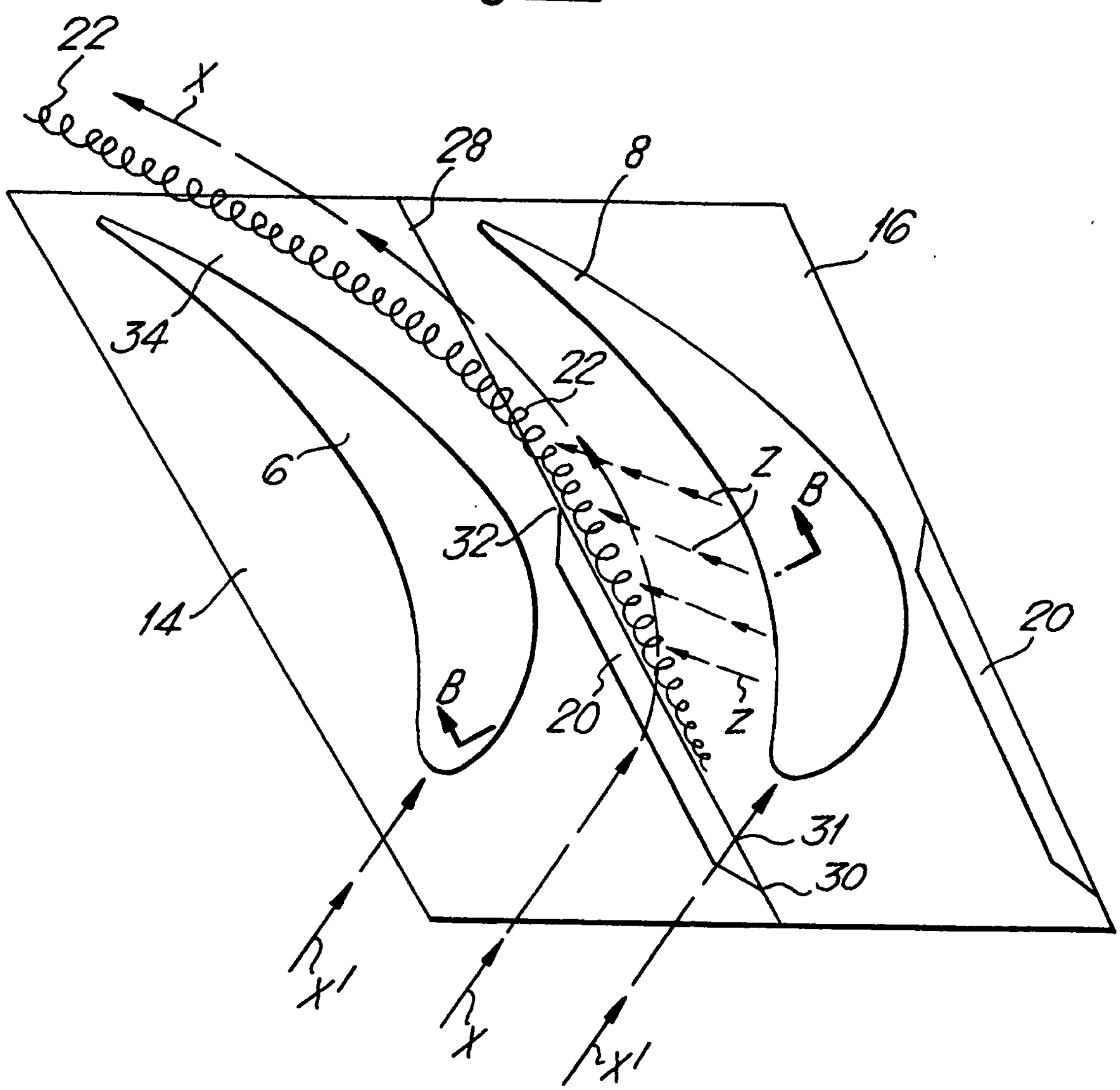


Fig. 3.

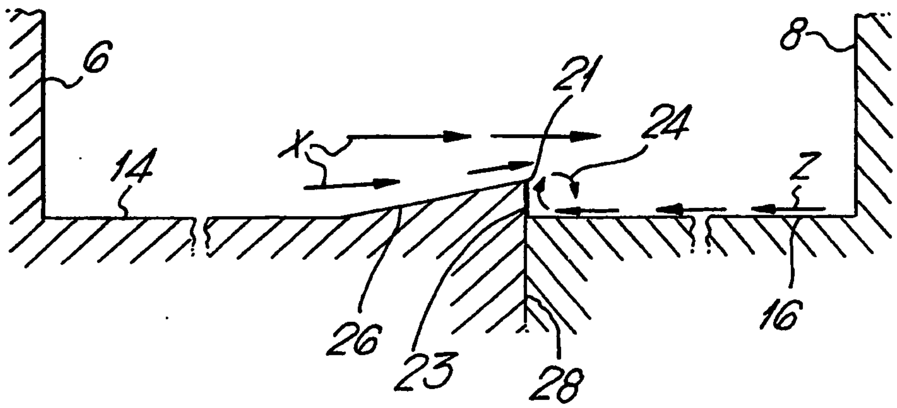
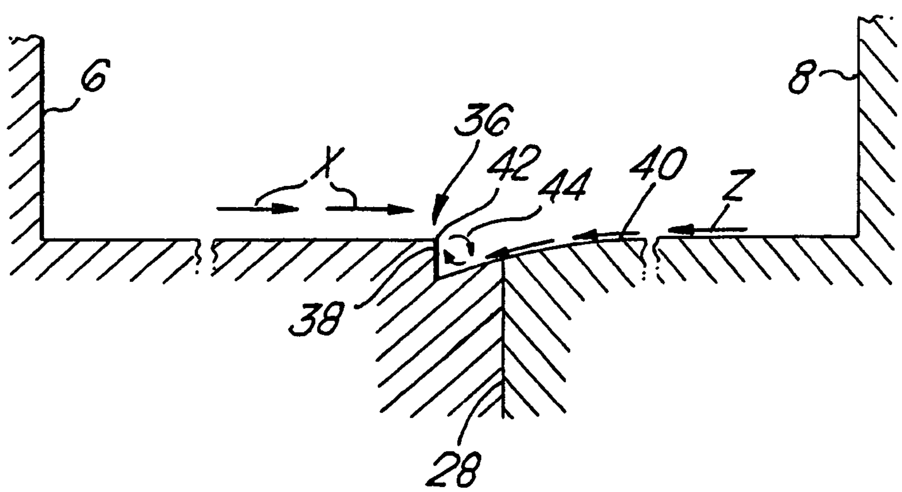


Fig. 4.



SPECIFICATION
Boundary Layer Flow Control

The present invention relates to boundary layer control in the flow passages of fluid flow machines. It particularly relates to the control of so-called "secondary flow", which is a cause of inefficiency in the compressors and turbines of axial fluid flow rotary machines, such as gas turbine aeroengines.

For the purposes of the present specification, the term "primary flow" will be used to refer to the high energy flow of a main body of fluid through a fluid flow passage. The exact direction of this primary flow may vary according to which location in the passage is under consideration. References to primary flows will be taken to include low energy flows in the boundary layer which move in the same direction, or substantially the same direction, as the high energy flow of the main body of fluid through the passage. The term "secondary flow" will be used to refer to low energy flows in the boundary layer which deviate significantly from the direction of the primary flow.

Axial flow gas turbine aeroengines are usually provided with stator blades or guide vanes situated within each compressor or turbine stage. Each pair of blades or vanes defines a flow passage for the high-energy primary flow of compressor or turbine gases. Low energy primary flows are also present in the flow passages, but these occur in the boundary layers of the blade or vane surfaces. However, because of the aerodynamic effects of the blade or vane aerofoils on the primary flow, some of the low energy boundary layer flow must be classed as secondary flow, since it deviates significantly from the local direction of primary flow.

As an example of the occurrence of secondary flow, consider a pair of stator blades or vanes defining a flow passage. As the primary flow approaches the leading edges of the aerofoils, the well-known "horseshoe"-shaped vortex is produced around the leading edges. This causes the primary flow to separate from the platform or shroud surfaces, leaving boundary layer areas near those surfaces which are little affected by the primary flow. Because the convex flank of one aerofoil is a low pressure area which faces a high pressure area caused by the concave flank of the adjacent aerofoil, a secondary flow proceeds from the concave flank of one aerofoil to the convex flank of the other *via* the intervening platform or shroud surfaces. This secondary flow is of course energised by the pressure differences between the aerofoil flanks and is in a direction transverse to the primary flow.

Since such secondary flows reduce the aerodynamic efficiencies of the flow passages by causing losses due to friction and turbulence, it is desirable to reduce their energy and extent as much as possible if this can be done without adversely affecting other flow characteristics of the passages.

According to the present invention, in order to control secondary flow near a flow surface of a flow passage in an axial fluid flow machine, said passage being adapt d to act aerodynamically upon primary flow therethrough said surface is provided with at least one elongate surface feature having an upstream end and a downstream end with respect to the primary flow, at least a portion of the surface feature at and near its upstream end extending transversely of both the primary and the secondary flows such that an edge portion of the surface feature acts as a vortex generator for primary flow passing thereover and produces alongside said surface feature an elongate vortex which intercepts and entrains said secondary flow, the orientation and interaction of the surface feature with respect to the primary flow being such that the elongate vortex becomes a vortical flow proceeding alongside the surface feature in a generally downstream direction with respect to the primary flow, whereby merging of the vortical flow with the primary flow is facilitated.

The at least one surface feature may be in the form of at least one step or ridge or fence-like structure having an elevation relative to the surface over which the secondary flow approaches the surface feature. Alternatively, the at least one surface feature may be in the form of at least one step or groove or other feature having a depression relative to the surface over which the secondary flow approaches the surface feature.

The fluid flow passage may be, for example, defined between a pair of stator blades or guide vanes in an axial flow compressor or turbine, the blades or vanes comprising aerofoil portions and associated platform or shroud portions. In this case those surfaces of the fluid flow passages subject to secondary flow will be the platforms or shroud surfaces, and the secondary flow will have a component of velocity directed along said surfaces from the concave flank of one aerofoil towards the circumferentially adjacent convex flank of the neighbouring aerofoil. The at least one surface feature should therefore extend across the platform or shroud chordwise of the aerofoils. It is important to the most efficient working of the invention that the upstream end of the surface feature should extend towards the leading edge of the platform or shroud sufficiently to cross the primary flow stagnation streamline of the relevant aerofoil leading edge. Conveniently, the surface feature is a step which is at least partly coincident with a split line between adjacent platform or shroud portions of adjacent vanes or blades. The top edge of the step constitutes the vortex generator and preferably the step is escarpment-like in configuration, having an abruptly rising portion which faces towards the concave face of the adjacent aerofoil, and a ramp portion whose surfac extends from the top of the abruptly rising portion to the surrounding surface level of the platform or shroud portion to gradually blend the st p therewith.

Embodiments of the invention will n w b described, by way of example only, with referenc to the accompanying drawings, in which:—

Figure 1 is a diagrammatic plan view of a pair of guide vane aerofoils which form a flow passage in a gas turbine engine;

Figure 2 is a diagrammatic plan view showing a pair of guide vanes having platforms modified according to the invention;

Figure 3 is a view on section line B—B in Figure 2;

Figure 4 is a view similar to Figure 3 showing an alternative embodiment of the invention.

The drawings are not to scale.

Referring to Figure 1, a pair of guide vane aerofoils 2, 4 are part of an annulus of such vanes disposed between two rotors in a multi-stage turbine in an axial flow gas turbine engine. The aerofoils 2, 4 are circumferentially spaced apart and, together with their associated radially inner and outer platforms (not shown) define a flow passage for the turbine gases, which have a primary flow through the passage approximately as indicated by arrows X.

Arrows X′ represent the stagnation streamlines in primary flow X. The stagnation points S are of course where the primary flow impinges on the leading edges of the aerofoils 2, 4. The stagnation points S are approximately where the already-mentioned horseshoe vortex (not shown) arises around the leading edge of each aerofoil, thus allowing secondary flow as shown by arrows Z to occur in the boundary layer on the surfaces of the radially inner and outer platforms. As explained previously, secondary flow Z is caused by the pressure difference between the convex and concave flanks of the aerofoils 2, 4.

When the secondary flow Z reaches the convex flank of aerofoil 4, it tends to spread radially across the surface of the flank towards its mid portion whilst forming a highly turbulent wake Y which reduces the capacity of the aerofoil to deflect the primary flow X satisfactorily.

Figure 2 shows a plan view of a pair of outer platforms 14, 16 having flow surfaces modified according to the invention in order to control secondary flow Z. The aerofoils 6, 8 are shown only as outlines at their intersection with the platform surfaces. Although the invention is now to be described with reference to its application to radially outer platforms 14, 16 it could equally well be applied to control secondary flow over the surface of radially inner platforms.

In Figure 2, flow lines X and Z again indicate primary and secondary flows respectively. Lines X′ again indicate the stagnation streamlines. In order to substantially prevent secondary flow Z from reaching aerofoil 6, an longate surface featur having an elevation relativ to the surrounding average level of the surface of the platforms 14, 16, is provided in the form of a ramped step 20.

As can be seen in Figure 3, step 20 is configured like a wedge or escarpment, having an abrupt step-face 23 and a ramp portion 26 which extends from the top of the step face 23 down to the surrounding surface level of the platform to gradually merge the step 20 into the general level of the platform. Step 20 extends transversely of the primary flow X, at least over part of its length nearest the leading edges of the vane platforms, 14, 16, and is also oriented transversely of the secondary flow Z. The step face 23 faces in a direction which has a downstream component relative to the general direction of the primary flow X, and also faces the concave flank of aerofoil 8.

Primary flow X is not abruptly disturbed as it flows up ramp portion 26 until it reaches edge 21, where ramp portion 26 and step face 23 meet. Edge 21 acts as a vortex generator, causing flow X to become a vortex 24 alongside step face 23, i.e. vortex 24 is produced on the "lee" side of the step with respect to the primary flow. The strength and position of the vortex 24 is such that it also entrains secondary flow Z as it approaches the step face 23, thus preventing all, or a substantial amount, of the secondary flow Z from reaching the convex side of the aerofoil 6.

Since there is a pressure drop between the leading and trailing edges of the platforms 14, 16 the vortex 24 becomes vortical flow 22 moving in the direction of this pressure drop. The vortical flow 22 thus moves downstream relative to the primary flow X towards the trailing edge of the platforms alongside the step face 23.

Conveniently, the step face 23 is, over at least part of its length, coincident with the split line 28 between the platforms 14, 16. In the embodiment shown in Figure 2, split line 28 and step face 23 are coincident from point 30 to point 32.

Another noteworthy feature of step 20 is its blending with the surrounding surface level of platforms 14, 16 at points 30 and 32, this being done by means of further ramp portions. This avoids possible adverse disturbance of the flow which could be caused if the step had blunt extremities. However, the full height of the step should preferably be attained at point 31, where step face 23 crosses stagnation streamline X′. Provided the step 20 extends for the appropriate distance upstream of the aerofoil leading edge, the vortical flow 22 will be produced preferentially instead of the horseshoe vortex.

Because that portion of the length of the step 20 which is nearest the platform leading edges makes a large acute angle with the local direction of primary flow X, it is a more efficient vortex generator than other portions of the step which are further away from the leading edges and which are aligned more exactly with the local direction of the primary flow. However, once established near the leading edges of the platforms, the vortical flow 22 continues to entrain further secondary flow for a considerable distance downstream of the leading edg s.

It might be thought that vortical flow 22 would adversely effect the aerodynamic performance of the flow passages formed by the guide vanes. However, the diameters of th vortices are

governed by the height of the step face 23 relative to th platforms 14, 16, and thus advers interaction of the vortices with primary flow X can be kept to a minimum by suitable design of the step. In an experimental model of the invention, a suitable height for step face 23 was found to be about 2 to 3 mm relative to the surrounding platform surfaces, and a suitable width was found to be about 9 to 12 mm. Further, the secondary flow Z which is entrained in vortical flow 22 is prevented from reaching the convex flank of aerofoil 6. This reduces the strength of flow Y (Figure 1), which in turn reduces the turbulence associated with it and increases the efficiency of the flow passage between aerofoils 6, 8. If the radially inner platform were also to be provided with steps similar to those described in relation to Figures 2 and 3, the efficiency of the passage would be increased even further.

There is, of course, no reason other than convenience to form the step to be coincident with the split line 28. It could be formed at any other suitable position and orientation on the platforms.

Hitherto, the invention has been described as applied to turbine guide vane platforms only, but it can also be applied to compressor stator blade platforms and shrouds.

Although the invention has been specifically applied herein as a surface feature in the form of an abrupt step 20, it is clear that the step face 23 could be less steep than shown herein; the invention could, for instance, take the form of a ridge, provided the ridge were to be of such form and orientation as to effect the production of the desired vortical flow. Alternatively, the step 20 with its ramped blending portions could be replaced by a simple fence-like structure, one of whose faces would correspond to step face 23. As still another alternative, instead of a surface feature having an elevation relative to the surrounding average level of the surface, a feature which is depressed relative to the surrounding average level of the surface, such as a groove or other elongate depression, could be utilised as a vortex generator according to the invention. An example of such a feature is given in Figure 4, which is a view similar to Figure 3.

In Figure 4, step 36 performs the same function as step 20 in Figures 2 and 3, but is of appropriately inverted shape, being depressed rather than elevated relative to the surrounding average level of the platform surface. Thus, the step face 38 faces in the same direction as step face 23, but the ramp portion 40 extends from the bottom of step face 38, which is below the general surface level of the platform, up to the platform surface level. Edge 42, where the step face 38 meets the platform surface, acts as the vortex generator for primary flow X, producing vortex 44, whilst secondary flow 2 flows d wn ramp portion 40 and is entrained in the vortex 44.

Whilst only one surface featur has been referred to in the above description, a plurality of such surface features could be utilised if necessary in order to adequately int rcept secondary flow over any particular surface.

Claims

1. A flow surface for a flow passage in an axial fluid flow machine, said passage being adapted to act aerodynamically upon primary flow therethrough and said flow surface being subject to secondary flow thereover, said flow surface being provided with at least one elongate surface feature having an upstream end and a downstream end with respect to the primary flow, at least a portion of the surface feature at and near its upstream end extending transversely of both the primary and the secondary flows such that an edge portion of the surface feature acts as a vortex generator for primary flow passing thereover and produces alongside said surface feature and elongate vortex which intercepts and entrains said secondary flow, the orientation and interaction of the surface feature with respect to the primary flow being such that the elongate vortex becomes a vortical flow proceeding alongside the surface feature in a generally downstream direction with respect to the primary flow, whereby merging of the vortical flow with the primary flow is facilitated.

2. A flow surface according to claim 1 situated in a flow passage defined between a pair of stator blades or vanes comprising aerofoil portions and associated platform or shroud portions.

3. A flow surface according to claim 2, comprising the platforms or shrouds of the blades or vanes, the at least one surface feature extending across the platform or shroud substantially chordwise of the aerofoils.

4. A flow surface according to claim 3, the surface feature at least partly coinciding with a split line between adjacent platform or shroud portions of adjacent vanes or blades.

5. A flow surface according to any one of claims 1 to 4, the at least one surface feature being in the form of at least one step or ridge or fence-like structure having an elevation relative to the surface over which the secondary flow approaches the surface feature.

6. A flow surface according to any one of claims 1 to 4, the at least one surface feature being in the form of at least one step or groove or other feature having a depression relative to the surface over which the secondary flow approaches the surface feature.

7. A flow surface according to claim 1 comprising a platform or shroud of a stator blade or vane, the flow passage being defined between a pair of said blades or vanes, the surface feature being a step the top edg of which constitutes the vortex generator.

8. A flow surface according to claim 7, the step being escarpment-like in configuration and having an abruptly rising portion which fac s the concav face of the adjacent blade or vane, and a ramp portion whose surface extends from the top of the abruptly rising portion to the surrounding surface

lev l of the flow surface to gradually bl nd the step ther with.

9. A flow surface having a surface feature substantially as described in this specification with reference to and as illustrated by the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1980. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.